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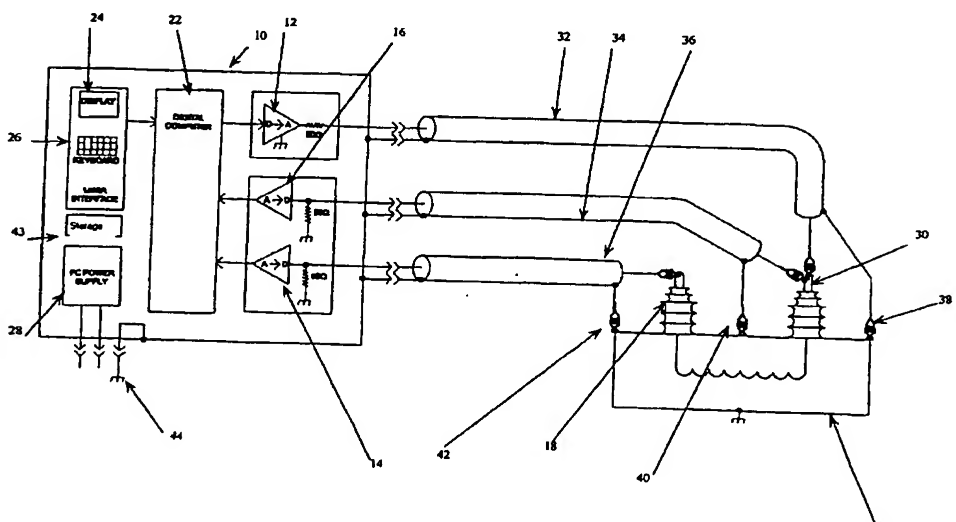
(54) Title: POWER TRANSFORMER TRANSFER FUNCTION TESTING



(57) Abstract: The invention comprises a system (10) and method for measuring the transfer function (TFA) of a transformer (20) across one or more frequency bands to detect changes in the physical state of the transformer. The process of measurement may be speeded up by taking a select number of measurements at discrete points across a frequency band. Using standard components, a system may be configured which is field portable and rugged.

WO 02/35248 A1

Power Transformer Transfer Function Testing

TECHNICAL FIELD

This invention relates to transformer transfer function testing.

BACKGROUND

Frequency response analysis (FRA) testing may be used to assess the mechanical condition of power and distribution apparatus. Specifically, transformers may be modeled by an equivalent circuit comprising resistance, inductance and capacitance (an R L C circuit). This unique circuit model characterizes a transformer's physical geometries. Changes in the transfer function of the model may indicate changes in the physical characteristics of the transformer, depending upon the frequency of the changed response.

FRA testing has been applied to large power transformers and reactors to detect core and winding movement and mechanical distortions, which may occur throughout the life of the equipment. Loss of mechanical integrity may occur due to (i) large electromagnetic forces due to fault currents passing through the windings, (ii) winding shrinkage causing release of clamping pressure, and (iii) during transformer relocations or other causes.

Tests have been performed in the past using relatively expensive general purpose laboratory equipment, which performs a sweep frequency series of measurements. Its size, cost and fragility make it difficult to use in the field.

SUMMARY

In one aspect, the invention provides a system for measuring the transfer function of a transformer at different frequencies. The system includes a portable computer, a signal generator, test leads and a voltage measuring device by which the computer may read voltage measurements from the transformer in response to an input signal to the

transformer from the signal generator. The system is self-contained in a field portable and ruggedized enclosure, assembled from standard components together with custom control software. Measurements are displayed on a graph plotting frequency against voltage.

In another aspect, the invention provides a method for measuring the transfer function of a transformer using a field portable computer, signal generator and voltage measuring device, applying a signal from the signal generator to the input side of a transformer, and measuring the voltage output from the transformer by the voltage measuring device. In another aspect, measurements are taken at selected discrete frequencies. Measurements are taken at discrete frequencies evenly spaced over a number of frequency bands. In still another aspect, four hundred discrete frequencies for each band are used. Measurements are displayed on a graph plotting frequency against voltage.

In an aspect, the invention includes a computer program which causes a computer, a signal generator connected to the input of a transformer, and a voltage measuring device connected to the output of the transformer, to perform a series of measurements of output voltage over a band of frequencies. In yet another aspect, measurements are taken at selected discrete frequencies. In still another aspect, measurements are taken at discrete frequencies evenly spaced over a number of frequency bands. In one implementation, four hundred discrete frequencies for each band are used. Measurements are displayed on a graph plotting frequency against voltage.

One or more aspects of the invention may include one or more of the following advantages.

Measurements may be taken with a field portable instrument custom assembled and programmed to do this specific task. Using standard components in a field ruggedized enclosure results in an instrument which is far less expensive and more reliable in the field. Taking measurements at selected discrete frequencies provides good results and reduces the time (compared to continuous sweep measurements) to conduct a test.

The details of one or more embodiments of the invention are set forth in the accompanying drawings and the description below. Other features, objects, and

advantages of the invention will be apparent from the description and drawings, and from the claims.

DESCRIPTION OF DRAWINGS

FIG. 1 is a block diagram.

FIG. 2 is a flow chart.

Like reference symbols in the various drawings indicate like elements.

DETAILED DESCRIPTION

A swept frequency method uses a network analyser or similar instrumentation configuration to apply a swept frequency signal to a winding and measure the attenuation and phase shift of the signal on passing through the winding or transferred between windings as a function of frequency according to the following formula:

$$\text{Attenuation} = 20*\log(V_{out}/V_{in}) \text{ for all frequencies}$$

where V_{out} is the output voltage and V_{in} is the input voltage.

Changes in the transfer function of a transformer over time can indicate changes in the mechanical condition of the device.

Referring to FIG 1, a transfer function analyser (TFA) 10 includes a signal generator 12 and a voltage measuring device 14 to read the voltage at the output 18 of the transformer 20 to be tested. A second voltage measuring device 16 is provided to measure the signal applied by the signal generator 12 at an input 30 of the transformer 20 to be tested. A digital computer 22 is connected to and controls voltage measuring devices 14 and 16 and the signal generator 12. The digital computer 22 has a display 24 and a keyboard 26 for user input. There is also a power supply 28 providing power to the computer 22 and peripheral devices 24, 12, 14, and 16. A coaxial test lead 32 connects the signal generator 12 to the transformer 20 input 30 and the shield to ground 38. Similarly, a second coaxial test lead 34 is connected to the second voltage measuring device 16 and the transformer 20 input 30 and the shield to ground 40.

Likewise, a third coaxial test lead 36 is connected to the input of the first voltage measuring device 14 and the output 18 of the transformer 20 being tested, and the shield to ground 42.

A bulk storage device 44 is provided to store the results of tests and to allow transfer of the results to other computers (not shown). The bulk storage device 44 may be a diskette, a tape or other similar device.

Signal conditioning (not shown) may be provided as necessary to improve the dynamic range of the measurements.

The signal generator 12 and voltage measuring devices 14 and 16 preferably are capable of operation without signal degradation over a frequency range from 1 Hz to 10 MHz. The signal generator 12 preferably is able to supply stimulus at least 10 Volts peak to peak over the specified bandwidth while maintaining current load.

In one embodiment, the two voltage measurement devices 14 and 16 are capable of measuring signals of amplitudes down to minus 85 dB with an accuracy of +/- 1 dB and a constant input impedance (50 ohms) over the above frequency range. Increasing dynamic range beyond -85 dB will improve the analysis. Adequate measurement cycles per frequency are needed to maximise signal to noise ratio (such as using bandpass filtering and averaging techniques) to ensure a quality measurement.

All test leads 32, 34 and 36 should have the same input impedance as the measurement circuit (50 ohms). The test leads preferably are made from low loss RF coaxial cable shielded with the shields capable of being earthed to the chassis. Suitable test leads and connectors are 50 ohm characteristic impedance cable type RG213/U UHF with type N connectors and cable type RG58/CU with type BNC connectors using N series to BNC adapters. The test leads 32,34 and 36 preferably are long enough to reach the bushings (60 ft), with the test equipment at ground level. The leads should be the same lengths.

To improve dynamic range it may de desirable to include an amplifier to expand the stimulus voltage to the maximum range allowable by the voltage measuring devices. The test equipment should be adequately grounded.

Referring to FIG 2, a block diagram showing the TFA process is shown. In one embodiment, the TFA configuration is set up 50 by connecting the leads to the TFA and the transformer to be tested. Under control of the computer, measurements are taken at a number of discrete frequency bands. The first band is selected 52, and then divided 54 into a desired number of evenly spaced discrete frequencies across the band. The signal is applied and measurement of the output taken 55. A number of measurements may be accumulated, as discussed above, to increase signal to noise ratio. If all frequencies in the band have not been tested 56 then the next frequency is selected 58 and the test continues by applying the next frequency and measuring the output 55. If all frequencies in the band have been tested 56 then a determination 60 is made whether all bands have been tested. If not, the next frequency band is selected 62 and the process 48 continues 54 by dividing the new band into the desired number of discrete points. If all bands and frequencies have been tested, then the measurements are stored 64 and the results may be shown on the display in a frequency vs. voltage plot.

Phase information may be obtained by appropriate timing of the measurements.

The system 10 can view and compare data from tests carried out at different times on a transformer, between different phases and tap winding positions of a transformer, and from different transformers. Different tests may be overlaid for comparison. The results of tests may be exported to any of a variety of computer programs such as spreadsheets, database programs and so forth.

The test setup and software is preferably recorded such that repeat measurements and measurements on similar transformers are done in the same way. Before measurements are made on the equipment to be tested, the correct operation of the measuring systems must be verified and demonstrated by connecting all test leads

together and measuring frequency responses without the equipment to be tested in the test circuit. The measured frequency responses for this setup should be flat (0 dB) to within ± 1 dB up to 10 MHz. The frequency response for this setup should be recorded along with the subsequent measurements made on the equipment to be tested.

A null stimulus measurement should also be performed in multiple locations of an energized high voltage substation to ascertain the expected interference levels. This test may be performed by measuring all three clamps connected together with the leads lying flat and straight, parallel to the high voltage lines. From this measurement degraded dynamic range will be calculated.

The transformer to be tested is disconnected from the associated electrical system at all terminals. The transformer to be tested is otherwise in its normal service condition, i.e. fully assembled and filled with oil. Preferably the transformer core should be free of residual magnetism, as residual magnetism influences FRA test results at low frequencies. If the residual magnetism is extreme, it may be necessary to demagnetize the core prior to FRA testing. Direct current tests may cause residual magnetism, hence FRA tests should be performed prior to any direct current tests.

Windings not under test whose terminals are available should be connected in a predetermined arrangement and this arrangement noted with the test data. If a winding is not brought out and internally earthed this should be noted with the test data. Terminals that are normally grounded in service will be grounded during testing (i.e. normally grounded wye-winding neutrals)

The test involves applying sinusoidal test signals to one terminal of the transformer under test and measuring this applied signal as well as the signal appearing at another terminal. Signals are applied and measured with respect to earth. The amplitudes and phases of the two signals are measured to determine the relative amplitude and phase shift changes between them. The basic measurement is of the attenuation and phase shift of a signal after having passed through the winding from the input to the output terminal. The measurements are made across designed bushings of

the transformer under test. This is achieved by applying test leads to bushing terminals.

The tests involve a series of measurements over a range of frequencies for each position of the test leads. The test leads are applied to each phase in turn. Tests are carried out on several arbitrary taps. It has been found that the entire range of frequencies need not be measured to obtain good results. In one implementation, the amplitude change and phase shifts are measured over five frequency bands and at 400 equally spaced frequencies within each band. The frequency bands are as follows:

10 Hz	to	2kHz
50Hz	to	20kHz
500Hz	to	200kHz
5kHz	to	2MHz
25kHz	to	10 MHz

Other frequency bands may be used. Experience to date suggests different frequency bands have different sensitivity to different mechanical deformation modes.

2 kHz scan is sensitive to core deformations, open circuits, shorted turns and residual magnetism.

20 kHz scan is sensitive mainly to bulk movement of windings relative to each other.

200 kHz and 10 MHz scans are sensitive mainly to deformation within windings.

Above 2 MHz is highly influenced by the lead geometries during test. Lead placement must be carefully controlled during subsequent tests for this high frequency band to be of use. On smaller distribution transformers, these higher frequencies are especially sensitive to winding movement.

Transformers may be single or three phase and consist of one to several windings with some windings having course and fine tapped sections. The windings may be connected in one of several configurations and neutrals of windings normally grounded in service connected to ground.

The phases of windings not under test are left floating. The neutrals of windings normally grounded under test are grounded. The one exception is when measuring across same side windings of a wye-connected winding. In order to perform this test, the neutral must be ungrounded.

Some transformers contain stabilizing, or internal delta windings not common to most transformers. It is possible to conduct a test on these windings. The test connection should be recorded for future test comparison. If the transformer under test has a stabilizing winding (normally delta connected), this can also be tested. The testing procedure will depend on what terminals are available. Similar considerations to the above apply to any windings which may have been installed by the transformer manufacturer for test purposes. Usually in such cases the test winding is not brought out to accessible terminals and is internally earthed. The existence of a test winding may or may not be identified on the transformer rating plate.

An electrostatic screen will have an effect on the responses of adjacent windings. The screen may be internally connected to one of the windings (usually at the neutral end) or a connection may be brought out of the tank for earthing externally. Where a separate electrostatic screen is provided it is recommended that this is earthed to the tank, since this will tend to remove any electrostatic interaction between the windings separated by it, and thereby reduce the influence of other windings on measured frequency responses. The presence of electrostatic screens and the way in which these are terminated should be recorded.

The test lead shields at the test equipment end of the leads should be connected via connectors to the test equipment frame and ground lead. The test equipment should be adequately grounded. Grounding of the earth leads will be ultimately achieved by connecting a ground lead from the chassis to ground. Ensure connections to the equipment under test and to earth are secure and of low impedance. Check continuity of test cables and cable sheaths.

The results are stored and made available in electronic form. For each frequency scan the final results are available in a computer file with records containing the following: frequency (in Hz), attenuation (in dB) and phase shift (in degrees) The results of tests should be in such a format that the following is possible; (i) comparison to other test results, (ii) comparison between different phases of windings, and (iii) comparison to other similar types of transformers.

A number of embodiments of the invention have been described. Nevertheless, it will be understood that various modifications may be made without departing from the spirit and scope of the invention. For example, different frequency bands may be chosen or different numbers of discrete frequencies within the bands. Accordingly, other embodiments are within the scope of the following claims.

WHAT IS CLAIMED IS:

1. A system for testing transformers comprising:

a computer having a keyboard, a display, storage and removable storage device;

a signal generator, having an output capable of producing an electrical signal at a plurality of frequencies, the signal generator connected to the computer and the output frequency of the signal generator controllable by the computer;

first and second voltage measuring devices each connected to and controlled by the computer and each having an input for the computer to read the voltage at the input;

a first coaxial test cable having a first ground connection and first lead to connect the output of the signal generator to an input of an electrical transformer;

a second coaxial cable having a second ground connection and a second lead to connect the input of the electrical transformer to the at least one voltage measuring device; and

a third coaxial cable having a third ground connection and a third lead to connect an output of the electrical transformer to the at least one voltage measuring device

2. The system of claim 1 in which the computer, the signal generator and the voltage measuring devices are installed into a portable enclosure.

3. A method of testing a transformer comprising:

providing a computer, a removable data storage system, a signal generator, a display and a first and a second voltage measuring device;

electrically connecting an output of the signal generator to an input of a transformer to be tested;

electrically connecting the input of the transformer to an input of the first voltage measuring device;

electrically connecting an output of the transformer to an input of the second voltage measuring device;

applying a signal from the signal generator under the control of the computer to the input of the transformer at a plurality of frequencies; and

measuring the output voltage of the transformer at each of the plurality of frequencies of the signal applied to the transformer.

4. The method of claim 3 wherein the computer, removable storage device, voltage measuring devices and signal generator are installed in a portable enclosure.

5. The method of claim 3 wherein the plurality of frequencies comprise discrete bands.

6. The method of claim 5 wherein the plurality of frequencies within each band are evenly spaced across each band.

7. The method of claim 6 wherein each band comprises 400 discrete frequencies.

8. The method of claim 5 wherein the bands comprise the frequency ranges of 10 Hz to 2kHz, 50Hz to 20kHz, 500Hz to 200kHz, 5kHz to 2MHz and 25kHz to10 MHz.

9. A computer program product stored on a computer readable medium, comprising instructions to cause a computer to:

control the output produced by a signal generator connected to the computer and which output is connectable to an input of a transformer having a transformer output;

read the measured voltage from a first voltage measuring device connected to the computer and connectable to the transformer output;

read the measured voltage from a second voltage measuring device connected to the computer and connectable to the input of the transformer;

take measurements of the output and input at a plurality of frequencies applied to the input; and

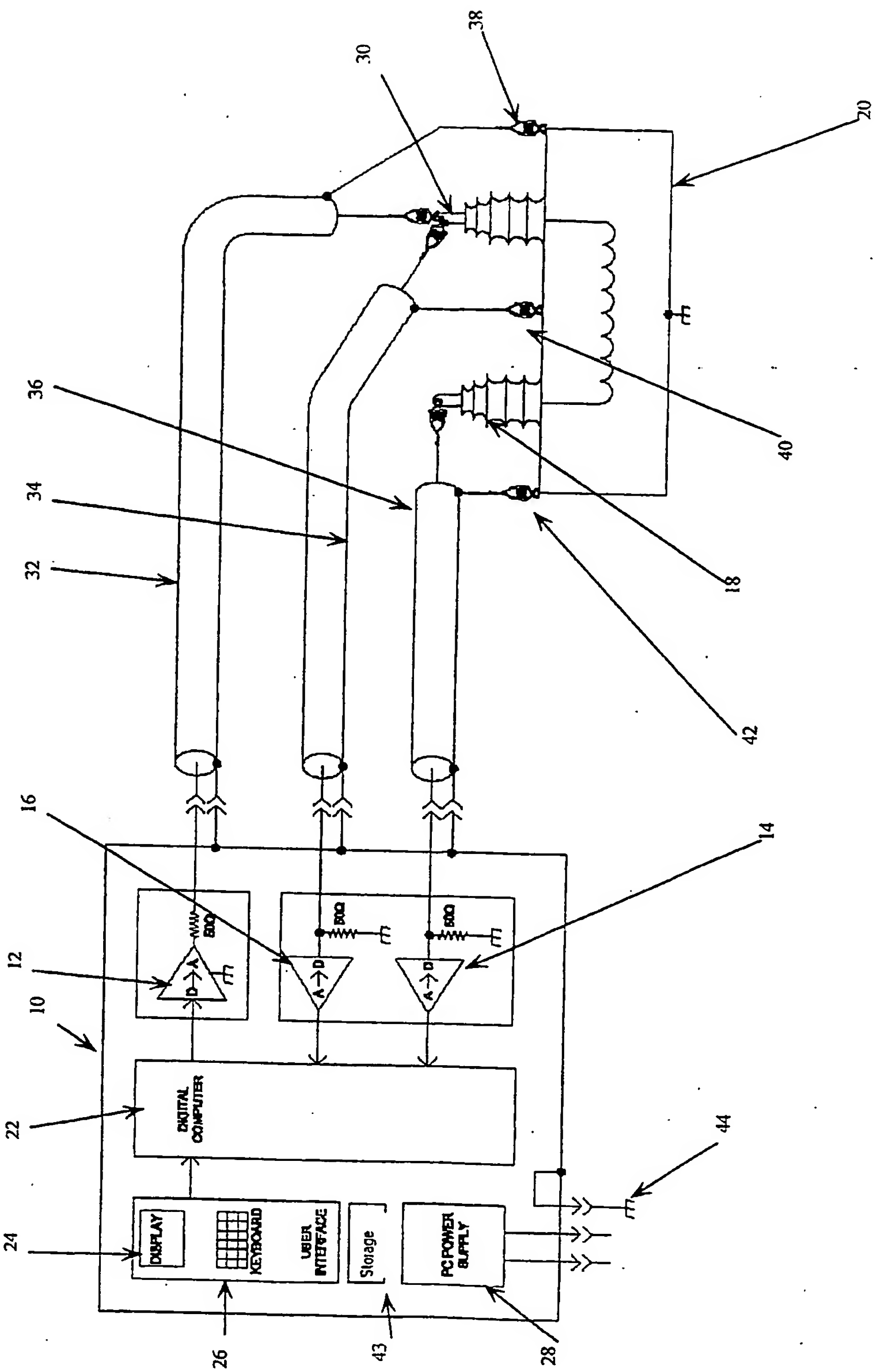
store the measurements.

10. The computer program product of claim 9 wherein the plurality of frequencies comprise discrete bands.

11. The computer program product of claim 9 wherein the plurality of frequencies within each band are evenly spaced across each band.

12. The computer program product of claim 11 wherein each band comprises 400 discrete frequencies.

13. The computer program product of claim 10 wherein the bands comprise the frequency ranges of 10 Hz to 2kHz, 50Hz to 20kHz, 500Hz to 200kHz, 5kHz to 2MHz and 25kHz to10 MHz.


DISPLAY
KEYBOARD
USER INTERFACE
Storage
PC POWER SUPPLY
DIGITAL COMPUTER
D→A
A→D
A→D
10
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16
18
20
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FIG. 1

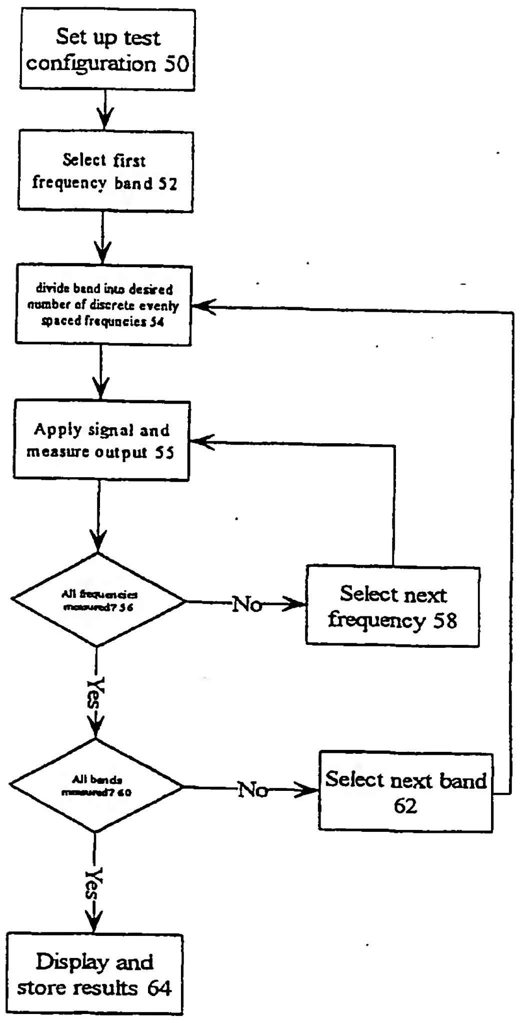
Set up test configuration 50
Select first frequency band 52
divide band into desired number of discrete evenly spaced frequncies 54
Apply signal and measure output 55
All frequencies measured? 56
No
Select next frequency 58
Yes
All bands measured? 60
No
Select next band 62
Yes
Display and store results 64

FIG 2

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US01/50916

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) : G01R 31/06

US CL : 324/547

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 324/106, 127, 726; 363/95

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5,455,506 A (MIMEAULT et al) 3 October 1995 (03.10.1995), entire document.	1-13
Y	US 4,857,856 A (COLEMAN et al) 15 August 1989 (15.01.1989), entire document.	1-13

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

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"&" document member of the same patent family

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Date of mailing of the international search report

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